

METHOD, SYSTEM, AND PROGRAM FOR MANAGING INPUT/OUTPUT (I/O)
PERFORMANCE BETWEEN HOST SYSTEMS AND STORAGE VOLUMES

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

[0001] The present invention is related to a method, system, and program for managing I/O performance between host systems and storage volumes.

2. Description of the Related Art

- 10 [0002] A storage service provider may maintain a large network, such as a Fibre Channel Storage Area Network (SAN), to service the computing needs for one or more customers. The SAN includes numerous host systems including the customer applications linked via a Fibre Channel fabric to one or more storage systems, such as or one or more interconnected disk drives configured as a Redundant Array of
- 15 Independent Disks (RAID), Just a Bunch of Disks (JBOD), Direct Access Storage Device (DASD), etc. Typically, a customer will pursue a service level agreement (SLA) with the storage service provider concerning the criteria under which network storage resources are provided, such as the storage capacity, network throughput, I/O response time, I/O operations per second, and other performance criteria under which
- 20 the network resources will be provided. In certain situations, multiple customers with different levels of requirements specified in their service level agreements will share the same network resources. This requires that the storage service provider monitor and manage the network resources to ensure that the different customer requirements specified in the different service level agreements are satisfied.
- 25 [0003] Accordingly, there is a need in the art to provide a method to specify the service level agreements and performance requirements to ensure that customers of these storage resources receive service according to the agreed upon performance criteria for providing the network resources.

SUMMARY OF THE PREFERRED EMBODIMENTS

[0004] Provided are a method, system, and program for managing a network providing Input/Output (I/O) paths between a plurality of host systems and storage volumes in storage systems. An application service connection definition is provided
5 for each connection from a host to a storage volume. At least one service level guarantee definition is provided indicating performance criteria to satisfy service requirements included in at least one service level agreement with at least one customer for network resources. Each service level guarantee definition is associated with at least one application service connection definition. Monitoring is performed
10 as to whether Input/Output (I/O) requests transmitted through the multiple I/O paths satisfy performance criteria indicated in the service level guarantee definition associated with the I/O paths.

[0005] In further implementations, multiple service level guarantee definitions indicating different performance criteria are associated with different sets of
15 application service connection definitions.

[0006] In still further implementations, an application service group is provided identifying a plurality of application service connection definitions, wherein associating the service level guarantee definition with the application service connection definitions comprises associating each service level guarantee definitions
20 with at least one application service group, wherein the application service connection definitions identified in the application service group are associated with the service level guarantee definitions with which their application service group is associated.

[0007] In additional implementations, monitoring whether Input/Output (I/O)
25 requests transmitted through the multiple I/O paths satisfy performance criteria indicated in the service level guarantee definition comprises: gathering performance information concerning I/O requests for each connection; selecting one service level guarantee definition; and for each connection identified by one application service connection definition associated with the selected service level guarantee definition,

comparing the gathered performance information for the connection with the performance criteria indicated in the selected service level guarantee definition.

[0008] Additionally, the operations among the I/O paths represented by the application service connection definitions associated with the selected service level
5 guarantee definition may be adjusted if the gathered performance information for the I/O paths does not satisfy the performance criteria.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Referring now to the drawings in which like reference numbers represent
10 corresponding parts throughout:

FIGs. 1 and 2 illustrate network computing environments in which embodiments of the invention are implemented;

FIGs. 3, 4, 5, 6, 7, and 8 illustrate an arrangement of information on I/O paths between hosts and storage volumes and service level requirements providing
15 performance criteria for service level agreements and associations therebetween in accordance with implementations of the invention;

FIGs. 9, 10, 11, and 12 illustrate operations performed to utilize the information described with respect to FIGs. 3-8 to manage the network shown in FIGs. 1 and 2; and

20 FIG. 13 illustrates a computing architecture that may be used to implement the network components described with respect to FIGs. 1 and 2.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] In the following description, reference is made to the accompanying
25 drawings which form a part hereof and which illustrate several embodiments of the present invention. It is understood that other embodiments may be utilized and structural and operational changes may be made without departing from the scope of the present invention.

[0011] FIG. 1 illustrates a network computing environment in which embodiments of the invention are implemented. A plurality of host systems 2a, 2b, 2c including one or more application programs 4a, 4b, 4c are in communication with a plurality of storage systems 6a, 6b, 6c over a network 8, such as a Fibre Channel Storage Area Network (SAN). The host systems 2a, 2b, 2c may comprise any computing device known in the art, such as a server class machine, workstation, desktop computer, etc. The storage systems 6a, 6b, 6c may comprise any mass storage device known in the art, such one or more interconnected disk drives configured as a Redundant Array of Independent Disks (RAID), Just a Bunch of Disks (JBOD), Direct Access Storage Device (DASD), as a tape storage device, e.g., a tape library, or etc.

[0012] A virtualization controller 10 is a system that is connected to the SAN 8 and implements a virtualization layer 12 for the SAN 8 to present the storage space available in the storage systems 6a, 6b, 6c as one or more common virtual storage pools. The virtualization layer 12 maps the physical storage resources available in the storage systems 6a, 6b, 6c to virtual volumes in the virtualization layer 12. For instance, physical storage in different storage systems 6a, 6b, 6c can be organized in the virtualization layer 12 as a single virtual volume. The virtualization controller 10 further implements multiple performance gateways 14a, 14b.

[0013] Each Input/Output path between a host application 4a, 4b, 4c, and a storage system 6a, 6b, and 6c is assigned to a particular performance gateway 14a, 14b. The performance gateways 14a, 14b intercept the I/O command for the assigned path (e.g., host and application) and records performance data for the I/O command, such as access time, time to complete, I/O throughput, etc. Thus, any I/O commands and data transferred between the applications 4a, 4b, 4c and storage systems 6a, 6b, 6c, represented as common storage pools in the virtualization layer 12, are handled by the performance gateway 14a, 14b to which the path on which the I/O commands and/or data is transmitted. The performance gateway 14a, 14b sends any gathered performance data to a service level agreement (SLA) server 16. The SLA server 16 includes an SLA database 20 including information on I/O paths and the criteria for

different service level agreements. The SLA server 16 processes information in the SLA database 20 determine how to process the performance information received from the performance gateways 14a, 14b. The SLA server 16 includes a performance analyzer 22 to analyze the performance statistics received from the performance

5 gateways 14a, 14b. The performance analyzer 22 may generate reports on the results of measuring I/O performance with respect to I/O paths among the hosts 2a, 2b, 2c and the storage systems 6a, 6b, 6c. The throttling policies 24 include information that indicates how the SLA server 16 is to adjust I/O activity to optimize performance based on the performance information gathered at the performance gateways 14a,

10 14b. An service level agreement (SLA) client 28 communicates with the SLA server 16 using a protocol, such as the Hypertext Transfer Protocol (HTTP). A user or administrator may use the SLA client 28 to interface with the SLA server 16 to provide input on service criteria and access performance reports and statistics generated by the performance analyzer 22.

15 **[0014]** In certain implementations, the virtualization controller 10 may transmit the gathered performance data to the SLA server 16 over another network, such as a Local Area Network 26.

[0015] FIG. 2 provides a further illustration of the connection between the hosts 2a, 2b, 2c and the storage systems 6a, 6b, 6c. The paths from the host applications 4a,

20 4b, 4c connect to one of the performance gateways 14a, 14b, implemented in the virtualization controller 10, and from the performance gateways 14a, 14b to one virtual volume 30a, 30b, 30c, 30d implemented in the virtualization layer 12. Different host applications in one host systems may have different paths that are assigned to different or the same performance gateways. The storage in each virtual

25 volume 30a, 30b, 30c, 30d maps to one or more of the physical storage systems 6a, 6b, 6c. The connection 32 from the performance gateways 14a, 14b to the SLA server 16 (FIG. 1), which may comprise a LAN connection 26 (e.g., a TCP/IP connection), is also illustrated.

[0016] The SLA database 20 includes information on service level agreements between customers and the storage service provider that maintains the SAN network and storage resources. An administrator may use the SLA client 28 to input the information on the service level agreements. An application storage connection
5 (ASC) record would be maintained for each connection between a host system 2a, 2b, 2c and storage volume 30a, 30b, 30c, 30d in the SAN 8 that is established pursuant to a service level agreement. FIG. 3 illustrates the fields maintained in an application storage connection record 50 as including:

- 10 ASC Name 52: a unique name for an application storage connection (ASC) between one host and a storage volume, either virtual or physical.
- Host 54: a unique identifier of a host used to represent the host in the SAN 8, such as a world wide name (WWN) recognized in the Fibre Channel network.
- Performance Gateway 56: a port identifier in the performance gateway 14a, 14b monitoring a connection between the application host 2a, 2b, 2c and a
15 storage system 6a, 6b, 6c.
- Logical Volume 58: the name of a logical volume 30a, 30b, 30c, 30d or physical storage system 6a, 6b, 6c which the host 54 can access through the connection represented by the ACS record.

20 [0017] The storage service provider of the SAN 8 may further define, using the SLA client 28, one or more application storage groups (ASGs), each identifying one or more application storage connections, where a single application storage connection, represented by one ASC record 50, may be included in multiple application storage groups. FIG. 4 illustrates an application storage group (ASG) record 70 as including
25 a unique ASG name 72 and the unique identifier of one or more application storage connections (ASCs) 74 assigned to the group. In determining which application storage connections to assign to an application storage group, the administrator may assign ASCs that all must satisfy a minimum performance criteria defined within the

one or more service level agreements that specify performance criteria for the application storage connections within the group.

[0018] The storage service provider may further define, using the SLA client 28, a plurality of service level guarantees that define performance guarantees defining the level of performance the storage service provider must provide pursuant to one or more service level agreements. A defined service level guarantee may apply to one or more application storage groups to define the level of service and performance expected of the connections identified by the application service connections (ASCs) included in the application service groups (ASGs) to which the service level guarantee is assigned. FIG. 5 illustrates information included in a service level guarantee record 90, including:

Service Level Guarantee (SLG) Name 92: a unique name of the service level guarantee.

Service Level Guarantee Class 94: the network storage service provider may define classes that describe the nature of the performance specified for the service level guarantee, such as standard for general applications; premium transaction for transactional applications that require high I/O operations per second; and premium throughput for applications that require high throughput, e.g., megabytes per second.

Priority 96: a numeric representation of the priority of the SLG, from high to low.

Evaluation Interval 98: the time interval during which performance is evaluated. This value may indicate a number of units and a choice of time, such as five evaluations per hour, etc.

Percentage Guarantee 100: a percentage of the I/O operations that shall meet the defined performance requirements during the evaluation period.

Mean Response Time (MRT) 102: a mean response time for each I/O operation in milliseconds (MS).

Normalized Delivered I/O (NDI) 104: a normalized number of I/O operations per second per contracted storage unit, e.g., 100 gigabyte of contracted capacity (IOPS/100 GB).

5 Normalized Delivered Throughput (NDT) 106: a normalized number of megabytes per second per contracted storage unit, e.g., 100 gigabytes of contracted capacity.

10 [0019] In certain implementations, different performance characteristics, e.g., MRT, NDI, and NDT, may be specified for each performance class, e.g., standard, premium transactions, premium throughput. The NDI 104 and NDT 106 are demand metrics in that their value depends on the demand of the customer workload whereas the MRT is a delivery metric and is a measure of the quality of the service regardless of the workload. The SLA server 16 would compare the actual measured performance metrics with the demand and response time criteria specified for the service level

15 guarantee. For instance, if demand is less than agreed upon limits, then the response time is guaranteed to be less than the agreed upon MRT and the service level agreement performance criteria is met. However, when demand exceeds agreed upon limits, i.e., the actual throughput or I/Os per second exceeds the agreed upon limits, then the I/O access is exempt from the mean response time (MRT) requirement.

20 [0020] Another relational layer is the service level commitment (SLC) defined by the storage service provider which is used to apply one defined service level guarantee (SLG) to one or more application service groups (ASG) for a particular customer having multiple hosts connected to the SAN 8. FIG. 6 illustrates a service level commitment (SLC) record 120 as including:

25 SLC Name 122: a unique name of the service level commitment.

Customer 124: name of the customer to which the assigned service level guarantee applies.

SLG Name 126: the name of a defined service level guarantee (SLG) 90 providing commitments for the named customer.

ASG Names 128: the name of one or more appellation service groups including application service connections for the customer to which the SLG will apply.

5 Retention Interval 130: the time period during which the system will gather statistic data of ASGs defined by value and unit.

10 Reporting Interval 132: The interval at which the system will send collected statistics on performance data of the ASGs, defined by value and unit, to the performance analyzer 22 in the SLA server 18. The collection and reporting intervals 130 and 132 may be adjusted.

15 **[0021]** The storage service provider may review a service level agreement for a customer and then assign, using the SLA client 28, service level commitments to application service groups of application service connections for a customer by defining service level commitments for that customer. The storage service provider
20 may enter information on connections (ASCs), groups of connections (ASGs), performance criteria (SLGs), and the relation therebetween (SLCs) at the SLA client 28, where the defined ASCs, ASGs, SLGs, and SLCs are stored in the SLA database 18. Each instance of the above records (e.g., ASC, ASG, SLG, and SLC records) may be implemented in an Extensible Markup Language (XML) file or records within a database.

25 **[0022]** FIG. 7 illustrates a relationship among the different above defined records. A plurality of application service connection (ASC) 150a, 150b....150l, each defining a connection from a host to one logical or physical storage volume 152a, 152b, 152c, and 152d, are grouped within application service groups 154a, 154b, and 154c, as shown by the connecting lines. Different service level guarantees 156a, 156b, one heavy and light, respectively, are associated with different of the application service groups 154a, 154b, 154c through service level commitment 158a, 158b associations.

[0023] When the service level agreement (SLA) server 16 determines that certain service level guarantees are not being satisfied for an application service group

(ASG), then the SLA server 16 may apply a predefined throttling policy 24 to alter and effect the performance. This throttling policy may cause the performance gateways 14a, 14b that manage the I/O paths to delay the I/O transmitted through I/O paths that are over performing associated service level guarantees to improve the performance of I/O paths that are underperforming.

5 [0024] FIG. 8 illustrates how the service level agreement server (SLA) 16 gathers performance data by application service group 170. The SLA server 16 will gather performance data for each application service connection (ASC) 172a, 172b...172n (FIG. 8) defined for the application service group (ASG) 170, including the measured response times 174a, 174b...174n for I/O operations, the number of I/O operations per second per 100 gigabytes of contracted capacity 176a, 176b...176n (IOPS/100GB), 10 and the number of megabytes per second per 100 gigabytes of contracted capacity 178a, 178b...178n (MBPS/100GB). Such information may be maintained for each defined ASG and the ASCs defined therein.

15 [0025] FIG. 9 illustrates operations performed by the SLA server 16 when receiving (at block 200) performance data gathered by one performance gateway 14b, the SLA server 16 locates (at block 202) the performance data for the ASC 172a, 172b...172n (FIG. 9) for which the performance data was received. The located performance data for the ASC 172a, 172b...172c is updated with the new received performance data. In this way, the performance data may maintain each instance of a measured performance parameter, such as response time for each I/O request, I/O operations per second, I/O throughput.

[0026] FIG. 10 illustrates operations performed by the SLA server 16 to collect reporting data according to time limitations included in the service level guarantees records 90 in the SLA database 20. For each defined SLC record 120 (FIG. 6) (at 25 block 220), the SLA server 16 will gather (at block 222) after the collection interval all the performance data for ASCs 172a, 172b...172n within the ASG 170 identified in the ASG name field 128 (FIG. 6) in the SLC record 120. Further, at the expiration of the reporting interval 132 for each SLC record 120, the SLA server 16 will collect

- (at block 224) all the performance data for ASCs 172a, 172b....172n, including the measured response times 174a, 174b...174n, measured IOPS/100GB 176a, 176b...176n, and measured MBS/100GB 178a, 178b...178n, within the ASG 170 identified in the ASG name field 128 of the SLC record 120 being processed, and
- 5 send such gathered statistics and performance data to the SLA client 28. The SLA server 16 may run a timer, continually reset upon expiration, for each collection interval 130 and reporting interval 132 identified in each SLC record 120 to perform steps 222 and 224 when the timer runs to zero. The timers would be reset and run again
- 10 **[0027]** FIGs. 11 and 12 illustrate logic implemented in the SLA server 16 to determine whether application service connections (ASCs) 150a, 150b....150l (FIG. 7) satisfy service level guarantee definitions 156a, 156b with which they are associated. Upon the expiration (at block 250) of the evaluation interval 98 for one SLG record 90 (FIG. 5), the SLA server 16 would begin operations to determine
- 15 whether the performance criteria for the SLG 156a, 156b are being satisfied with respect to the application service connections (ASCs) 150a, 150b...150l to which the service level guarantees apply. The SLA server 16 may initialize a timer for each evaluation interval 98 in each SLG record 90 to determine when to initiate the performance checking procedure. The SLA server 16 then determines (at block
- 20 251) the service level commitment (SLC) 158a, 158b whose SLG name field 126 (FIG. 6) identifies the SLG 156a, 156b whose evaluation timer expired. From the ASG name field 128 in the record 120 for the determined service level commitment (SLC) 158a, 158b, the SLA server 16 determines (at block 252) the one or more application service groups (ASG) 154a, 154b, 154c that are associated with the
- 25 service level guarantees (SLG) 156a, 156b to check.
- [0028]** The SLA server 16 then performs a loop at blocks 254 through 268 for each application service connection (ASC) 150a, 150b...150l in each of the determined one or more application service groups (ASG) 154a, 154b, 154c. At block 256, the SLA server 16 determines the performance requirements for the ASC *i* from the service

level agreement (SLG) 156a, 156b being checked, including the mean response time (MRT) 102, the normalized delivered I/O (NDI) 104, and the normalized delivered throughput (NDT) 106 (FIG. 5). These desired performance criteria may be specified as a range, such as greater and/or less than a value and unit. The SLA server 16 then determines (at block 258) whether the percentage of I/Os for ASC *i* that satisfies the MRT requirement 102 is greater than or equal to the percentage guarantee 100 for the SLG being checked. As discussed, the ASC performance statistics 172a, 172b...172n would include the measured response times 174a, 174b...174n for a measured time interval. The SLA server 16 may process these measured response times to determine the percentage of such response times that satisfy the MRT requirement 102 to accomplish the step at block 258.

[0029] If (at block 258) the measured response times do satisfy the percentage guarantee 100, then the SLA server 16 determines (at block 260) whether the demand level for the connection represented by ASC *i* is less than the agreed demand level. As discussed, the measured demand is determined from I/O operations per second 176a, 176b....176n and the number of megabytes per second 178a, 178b...178n measured for the ASC *i* and whether this measured activity falls within the agreed upon demand parameters, e.g., the normalized delivered I/O (NDI) 104 and the normalized delivered throughput (NDT) 106 indicated in the service level guarantee 90 record being checked. If (at block 260) the demand satisfies agreed upon SLG demand parameters, then a determination is made (at block 262) whether the mean response time (MRT) of the measured response times 174a, 174b...174n (FIG. 8) for ASC *i* is less than or equal to the MRT 102 in the SLG record 90 (FIG. 5) for the service level guarantee being checked. If (from the no branch of block 258) the measured response time does not satisfy the percentage guarantees 100 or if (from the no branch of block 262) the measured mean response time (MRT) does not meet the agreed criteria indicated in the MRT field 102 of the SLG record 90, then an indication is made (at block 264) that ASC *i* is underperforming. Otherwise, if the performance guarantee is satisfied (from the yes branch of block 258) and the demand

does not exceed agreed upon levels (from the yes branch of 260), then indication is made (at block 266) that the ASC *i* is over performing with respect to the SLG requirements. Control then proceeds (at block 268) back to block 254 to consider any further application service connections (ASCs) 150a, 150b...150l in the ASGs 158a,
5 158b...158n to which the SLG 156a, 156b applies.

[0030] After processing all the ASCs, control proceeds (at block 270) to block 280 in FIG. 12 where the SLA server 16 collects (at block 280) the results of performance information and stores that information in the SLA database 20. The performance analyzer 22 receives the information for ASCs in ASGs, and determines the actions
10 that need to be performed. If (at block 282) no ASCs are under performing, then the SLA server 16 signals (at block 284) the performance gateway(s) 14a, 14b (FIGs. 1 and 2), to which the just considered application service connections (ASCs) 150a, 150b...150l are connected, to end throttling for any of the ASCs that are determined not to be under performing. This will end any throttling of ASCs which are not
15 performing at the level specified in the checked service level guarantee (SLG), which meets the criteria specified in the service level agreements associated with the ASCs. If certain of the considered ASCs 150a, 150b...150l are under performing (from the no branch of block 282) and some are over performing (at block 286), then the SLA server 16 signals (at block 288) the performance gateways 14a, 14b, to which the just
20 considered ASCs are connected, to throttle over performing ASCs in the ASG(s) associated with the SLG being checked to slow down their performance and direct network storage resources toward the under performing ASCs associated with the SLG. The signaled performance gateways 14a, 14b may delay forwarding I/O requests transmitted on the over performing ASCs to improve the performance of the
25 I/O requests transmitted on the underperforming ASCs by giving priority to I/O requests transmitted on the under performing ASCs. The performance gateway 14a, 14b may use any throttling technique known in the art to direct resources away from over performing ASCs to the under performing ones.

[0031] If (from the no branch of block 286) there are under performing ASCs, but no over performing ASCs to throttle, then the SLA server 16 generates (at block 290) an alert to notify the storage service provider of the underperforming ASCs. The storage service provider may be notified through the admin client 18.

5 **[0032]** FIG. 13 illustrates an implementation of the SLA server 16 and SLA client 18 in a web service based architecture. The SLA client 300 may include a web browser 302 that renders an SLA administrative graphical user interface (GUI) 304 through which the network administrator may interact with the SLA server 320. The SLA client 300 further includes a performance monitor 306 component that presents
10 the response time in real-time to the network administrator from the performance information gathered by the SLA server 320. The SLA server 320 includes an HTTP server 322 to enable communication with the client web browser 302 and a Java servlet 324 to transfer information received at the HTTP server 322 to an application server 326 and to transfer information from the application server 326 through the
15 HTTP server 322 to the client web browser 302. For instance, the application server 326 may transfer real-time performance data from the SLA database 328 to the client performance monitor 306.

[0033] The application server 326 further collects configuration requests and sends monitoring displays to and from the servlet 324, and passes requests to other
20 components. The SLA database 328 comprises a database manager and database that maintains the various defined ASCs, ASGs, SLGs, SLCs, service level agreements, etc., stores collected performance data, and generates reports. SLA services 330 may include the throttling policies and conduct performance analysis and the policy based throttling control.

25 **[0034]** In the described embodiments, the SLA server 16 attempts to automatically alter how I/O requests are processed to direct more network storage resources to ASCs that are not satisfying certain service level agreement criteria defined in service level guarantees. In certain implementations, this is accomplished by throttling or delaying the processing of I/O requests transmitted on ASCs that are over performing.

In this way, SLA server 16 may automatically adjust the network to rebalance the distribution of network resources away from application service connections that are over performing to under performing ASCs. This allows adjustments to the network to boost under performing I/O paths without having to add additional network storage
5 resources.

[0035] In web service based architectures, such as shown in FIG. 13, all the information within the SLA database may be implemented as XML files created by the storage service provider at the SLA client 28. FIG. 14a illustrates how the service level agreement elements, such as the ASGs and ASCs are defined in an XML
10 format, where the ASGs and ASCs are tagged elements having as attributes the information. FIG. 14b illustrate how the service level commitment information is implemented in the XML format wherein a SLC element has various attributes that define the information for the service level commitment (SLC). There may be multiple SLC elements in one XML document or dispersed across multiple XML
15 documents. Similarly, FIG. 14c illustrates how the service level guarantee (SLG) information is implemented in the XML format with a SLG element including attributes defining the values for the specific SLG element. There may be multiple SLG elements in one XML document or dispersed across multiple XML documents.

20 Additional Implementation Details

[0036] The network management described herein may be implemented as a method, apparatus or article of manufacture using standard programming and/or engineering techniques to produce software, firmware, hardware, or any combination thereof. The term "article of manufacture" as used herein refers to code or logic
25 implemented in hardware logic (e.g., an integrated circuit chip, Programmable Gate Array (PGA), Application Specific Integrated Circuit (ASIC), etc.) or a computer readable medium, such as magnetic storage medium (e.g., hard disk drives, floppy disks,, tape, etc.), optical storage (CD-ROMs, optical disks, etc.), volatile and non-volatile memory devices (e.g., EEPROMs, ROMs, PROMs, RAMs, DRAMs,

SRAMs, firmware, programmable logic, etc.). Code in the computer readable medium is accessed and executed by a processor. The code in which preferred embodiments are implemented may further be accessible through a transmission media or from a file server over a network. In such cases, the article of manufacture

5 in which the code is implemented may comprise a transmission media, such as a network transmission line, wireless transmission media, signals propagating through space, radio waves, infrared signals, etc. Thus, the “article of manufacture” may comprise the medium in which the code is embodied. Additionally, the “article of manufacture” may comprise a combination of hardware and software components in

10 which the code is embodied, processed, and executed. Of course, those skilled in the art will recognize that many modifications may be made to this configuration without departing from the scope of the present invention, and that the article of manufacture may comprise any information bearing medium known in the art.

[0037] The described embodiments define a particular arrangement of information

15 on I/O paths between hosts and storage (application service connections), an arrangement of I/O paths (application service groups), service level criteria (service level agreements), and a service level commitment that associates service level criteria with particular I/O paths. In alternative implementations, this relationship of service level agreement criteria to actual host I/O paths may be represented in

20 alternative relationships and data structures than described herein.

[0038] In the described implementations, the I/O paths between host and storage are handled by performance gateways implemented in a virtualization controller. In alternative implementations, the monitoring of I/O requests and I/O paths may occur at either the host or storage level, thereby avoiding the need for the use of a separate

25 virtualization controller and virtualization layer.

[0039] The storage volume associated with an application storage connection may comprise a virtual volume managed in a virtualization layer or a physical volume on a storage device.

[0040] FIGs. 11 and 12 describe specific operations occurring in a particular order. In alternative implementations, certain operations may be performed in a different order, modified or removed. Moreover, steps may be added to the above described logic and still conform to the described implementations. Further, operations
5 described herein may occur sequentially or certain operations may be processed in parallel. Yet further, operations may be performed by a single processing unit or by distributed processing units.

[0041] FIG. 15 illustrates one implementation of a computer architecture 400 of the network components shown in FIGs. 1,2, and 7, such as the host, storage systems,
10 virtualization controller, etc. The architecture 400 may include a processor 402 (e.g., a microprocessor), a memory 404 (e.g., a volatile memory device), and storage 406 (e.g., a non-volatile storage, such as magnetic disk drives, optical disk drives, a tape drive, etc.). The storage 406 may comprise an internal storage device or an attached or network accessible storage. Programs in the storage 406 are loaded into the
15 memory 404 and executed by the processor 402 in a manner known in the art. The architecture further includes a network card 408 to enable communication with a network. An input device 410 is used to provide user input to the processor 402, and may include a keyboard, mouse, pen-stylus, microphone, touch sensitive display screen, or any other activation or input mechanism known in the art. An output
20 device 412 is capable of rendering information transmitted from the processor 402, or other component, such as a display monitor, printer, storage, etc.

[0042] The foregoing description of the implementations has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are
25 possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto. The above specification, examples and data provide a complete description of the manufacture and use of the composition of the invention. Since many

implementations of the invention can be made without departing from the spirit and scope of the invention, the invention resides in the claims hereinafter appended.